PRELIMINARY EXPERIMENTAL STUDY OF DOUBLE-SKINNED FAÇADE

W.K. Chow and W.Y. Hung
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

G.W. Zou, H. Dong and Y. Gao
Department of Building Engineering, Harbin Engineering University, Harbin, Heilongjiang, China

(Received 20 February 2004; Accepted 14 April 2004)

ABSTRACT

Fire hazard of the new architectural feature – double-skinned façade was examined experimentally. Full-scale burning tests on part of the design feature were carried out in a facility developed in a remote area of Northeast China. Before testing with glass panels, wood panels were used for preliminary tests. A total of 10 tests were performed. Surface temperature and heat flux received on the test panels are presented. Cracking patterns found on the glass panels are also described. Preliminary results give the possible smoke movement pattern inside the air cavity. Further detailed investigations should be carried out.

1. INTRODUCTION

There are many buildings with glass curtain wall in “cities group” of the Far East [1]. However, the increase in the cooling load of those buildings in tropical areas is a concern. Strong sunlight leads to using solar shading devices with indoor illumination by artificial lighting. Therefore, double-skinned façades are proposed to overcome the problems inherent in glazed wall and for environmental benefits [2,3]. Solar heat gain coefficient and thermal transmittance are found to be reduced by using an extra layer of glass. Convection inside the cavity induced by mechanical systems would take away solar heat gain. In addition, acoustic attenuation can be achieved by the double façade system.

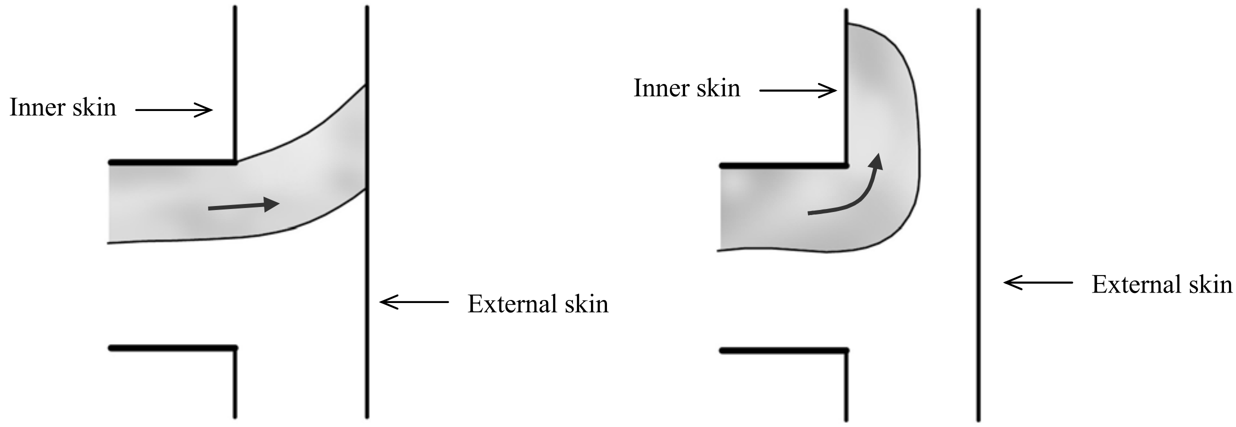
However, glass is found to be less resistant to heat than opaque wall such as concrete. Studies on glass performance were reported [e.g. 4,5] worldwide from which safety of glass becomes a query since the capacity of glass to resist thermal stress is not high enough. Breakage of glass under heat exposure is common. Previous works are useful as references on breaking glass scenarios. However, the new architectural feature is different from double-glazing system, though there are also two layers of glass pane. The distance between two layers of glass can be as far away as 2 m and the void is extended vertically through stories or even the whole building height. It is already known from the literature [4] that a single glazing would probably break and fall out under certain conditions, say about 400 °C to cause fallout of 6 mm clear float glass. If the internal glass wall of a double-skinned façade is broken at fire condition, smoke and flame moving out to the cavity would further damage the other part of the construction.

Since double-skinned façade has been a popular building feature lately in the local area, fire safety [6,7] is a concern that should be dealt with carefully. In fact, many of them failed to comply with the fire regulations. Investigation by experiments on the fire behavior of this building feature is necessary, in addition to using Computational Fluid Dynamics (CFD). Thermal performance of the glass panels on the adjacent floors and on the outer skin should be clearly understood. Smoke movement is the key phenomenon on fire safety. If hot smoke moves towards the outer skin, as in Fig. 1a, the outer glass panel might be cracked or even broken by heat or high pressure. Otherwise, the upper glass panel would be affected if smoke (or even flame) moves upwards, as shown in Fig. 1b. Breaking the outer glass panel is not as disastrous as breaking the upper one in giving a channel for spreading of smoke and flame to upper stories. For ordinary single-skinned curtain wall, smoke and toxic gases can be diluted and cooled down by the ambient air whilst for double-skinned façade, they are trapped inside the vertical air cavity which is at higher temperature than in the open space. In addition, pressure gradient inside the cavity would have significant effects on glass. All these suggested that full-scale burning tests should be carried out.

However, additional attention should be paid in carrying out full-scale burning tests. In Hong Kong (now the Hong Kong Special Administrative Region), it seems impossible to select a site for this purpose because of the extremely high land price.

There are also concerns on environmental protection in the dense urban area. Toxic gases and particles generated from the tests would be harmful to the citizens. In light of that, a remote site should be found. But the site should be easily accessed for delivery of goods and samples. Also, there must be water and electricity supply.

With the smooth reunification of the Special Administrative Region to China, there are much more open scientific developments. There is even stronger collaboration with China. An abandoned hall in a small town Lanxi in Harbin in Northeast China was rented as the laboratory to carry out the experimental study. The burning hall of 6 m high, 16.5 m long and 16 m deep, with a view shown in Fig. 2. Inside the hall, full-scale burning facilities on a double-skinned façade were constructed.



(a) Smoke moves towards outer skin of glass (b) Smoke moves towards inner skin of glass

Fig. 1: Smoke movement in double-skinned façade

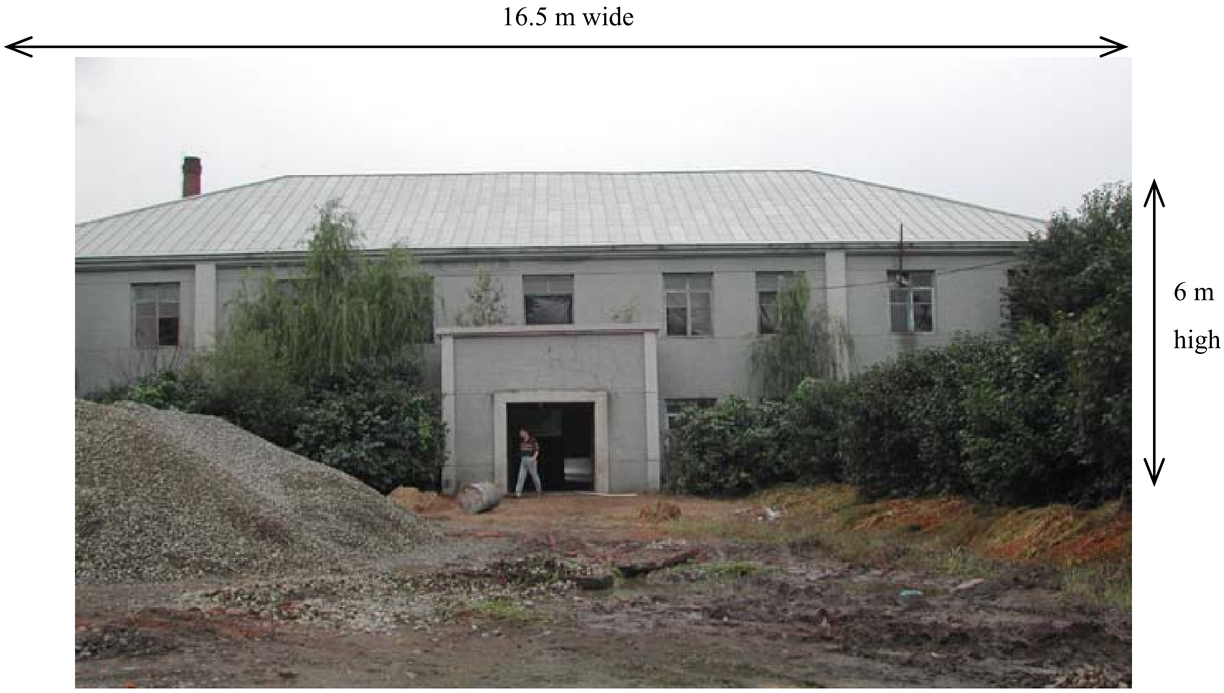
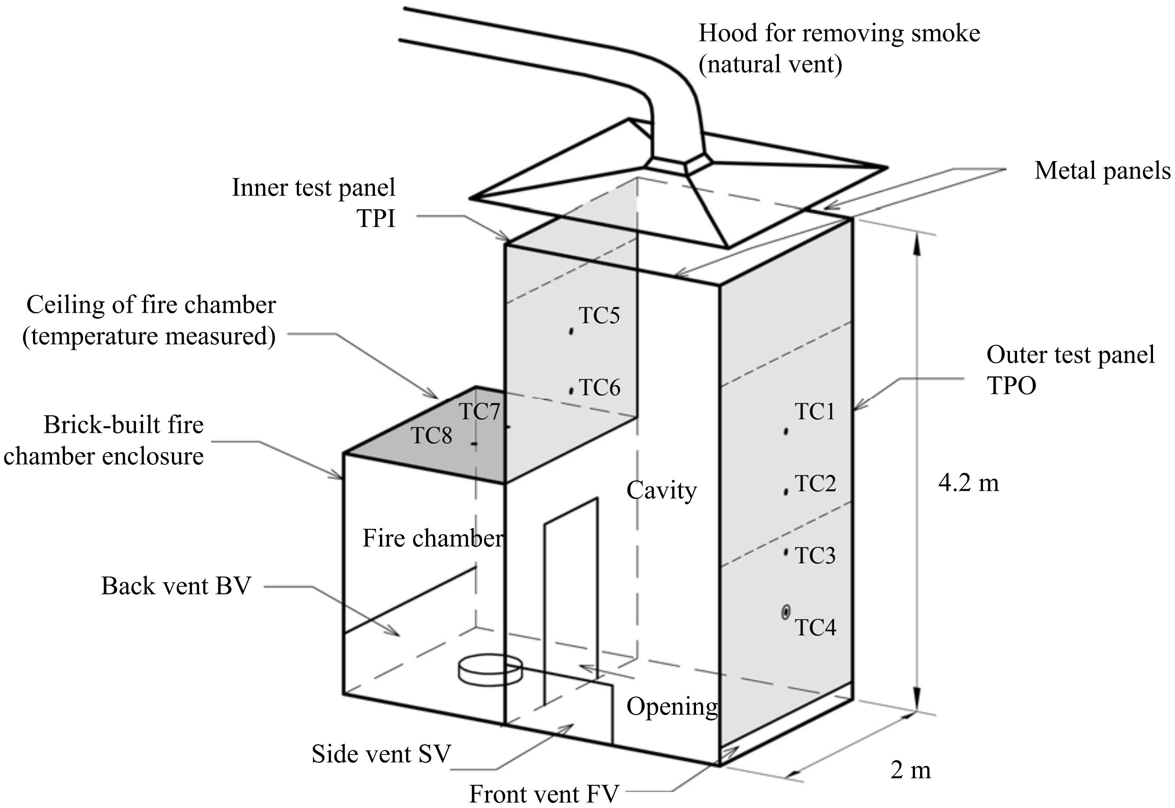


Fig. 2: External view of the burning hall in Lanxi

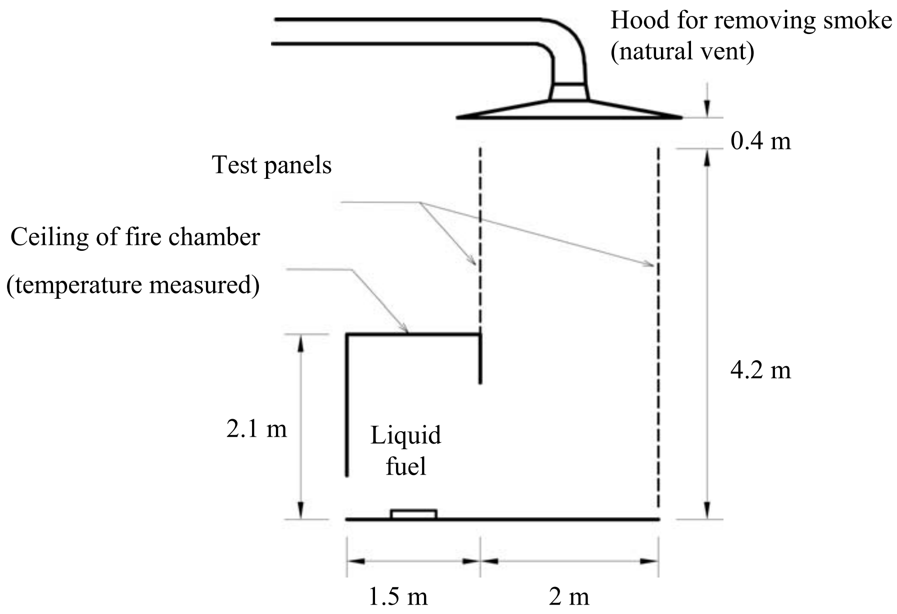
2. EXPERIMENTAL FACILITY

The behavior of glass panels and smoke movement in the air cavity of a double-skinned façade will be studied experimentally.

The experimental rig used was in an L-shape configuration with one fire room attached to a space demonstrating the cavity between the two glass panes of a double-skinned façade, as illustrated in Fig. 3. The fire chamber was 2 m wide, 1.5 m deep and 2.1 m high and the cavity was 2 m wide, 4.2 m high and 2 m deep. Test panels TPO and TPI were demonstrating the outer skin and inner skin of the upper story respectively while the fire chamber acted as an occupied space in which a fire broke out.



(a) Schematic diagram of test rig



(b) Sectional view

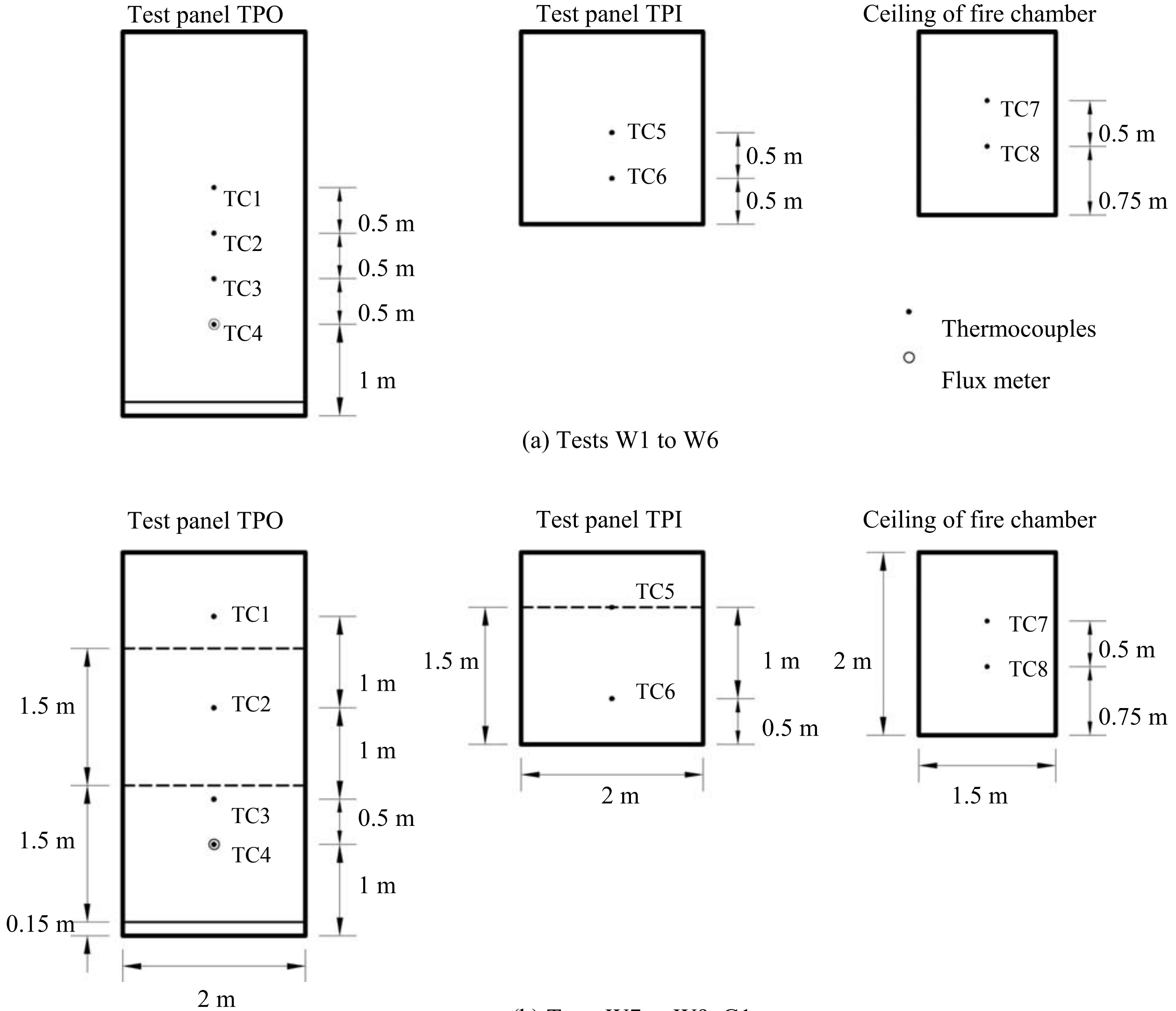
Fig. 3: Schematic diagram of the experimental setup

The opening of the fire chamber opening to the cavity can be taken as a new vent created by the breakage of glazed wall. The window adjacent to the fire origin can be easily broken by excessive absorption of heat. Glass pane would crack once its critical thermal stress is exceeded as reported in the literature [e.g. 4,5].

Fire protective coating was applied onto the inner surface of the wood panels to keep it for a longer time. The top of the cavity was open but a hood and exhaust duct were installed to remove the smoke and hot gases generated to the outside of the building by natural forces.

Thermocouples were attached to metal wires at fixed locations on the inner face of the test glass/wood panels to measure their surface temperature. A heat flux meter was installed on the inner surface of the panes to indicate the heat flux received on the panes. The number of thermocouples and flux meters was subject to their availability. In Fig. 4, the locations of thermocouples and flux meters were illustrated. Points TC1 to TC4 were located on the outer panel TPO; points TC5 and TC6 were located on the inner panel TPI and points TC7 and TC8 were used to measure the temperature at the top of the fire chamber.

As shown in Fig. 5, the enclosure of the fire room was constructed of brick which is not combustible. A vent of size 1.5 m high and 0.8 wide was left open to the cavity so that flame and smoke were able to pass through. The cavity wall was constructed by galvanized sheet steel. The two test wood panels were a species of poplar of 4 mm thickness. The test glass panels, of 3.5 mm thick, were common glass panels used for curtain wall available in the nearby regions. The available glass pane was 2 m wide and 1.5 m high, so that glass panes were cropped to suitable dimensions to compose full height of the walls, as shown in Fig. 4b.



(a) Tests W1 to W6

(b) Tests W7 to W9, G1

Fig. 4: Locations of thermocouples and heat flux meters

(a) Appearance

(b) Elevation

(c) Front view

Fig. 5: Pictures of the test rig

Liquid fuel was chosen for the test due to its reproducibility and ease of access. In the preliminary tests, gasoline of 1000 ml, 2000 ml, 3000 ml and 5000 ml were used and consequently 5000 ml was chosen for the final tests. The fire was of the size reaching flashover fire in such a fire room. Heat release rate of the fires with the same size was determined separately in a room calorimeter measured by the oxygen consumption method. The pool diameter was 0.5 m and it was placed at the centre of the fire chamber.

Because of limited budget, instead of installing glass panes, wood panels were used first to measure the preliminary data including the surface temperature and heat flux. It is known that the heat transfer coefficient of wood is different from that of glass since they have different performances in dealing with radiative heat flux. One is opaque while the other is transparent to thermal radiation. However, by certain assumptions and simulation analysis, it is possible to correlate the data from wood panels and those from glass panes so that some useful data on glass performance can be evaluated. Further, smoke movement can be observed by using wood panels under different chamber opening size, fire load and depth of cavity. Those factors would affect fire safety of this building feature. After obtaining several sets of data by using wood panels, glass panes were installed to investigate the heat performance of glass panels.

3. OBSERVATIONS

Ten tests were carried out with nine tests using wood panels (labeled as W1 to W9) and one using glass panel (G1). The first seven burning tests (W1 to W7) were carried out to determine the best setup, such as the location of openings and the fire load. The results are used as references later. The last three tests (W8, W9 and G1) were having identical amount of fuel and opening combinations which were evaluated from the previous tests. Tests W8 and W9 were compared with test G1 since their setups were identical except the panels at the inner and outer surface. Locations of thermocouples and flux meter of the two test panels are different among the ten tests with details shown in Fig. 4. The ceiling of the fire chamber was also fixed with thermocouples. Each burning test lasted for 10 to 15 minutes, starting from the preparation of fuel to burning up of the fuel.

Different openings were arranged on the test rig, namely a front vent FV of area 0.3 m^2 (0.15 m by 2.0 m), a back vent BV of 1 m^2 (0.5 m by 2.0 m), a side vent SV of 0.5 m^2 (0.5 m by 1.0 m) and a top vent of 4 m^2 (2.0 m by 2.0 m), as shown in Fig. 3a. In this way, different opening conditions were used in different tests, as shown in Table 1. The measured surface temperatures were different under different opening conditions. Different combinations of openings were used in the preliminary tests, say opening the back and top vents in test W1, and opening the side and top vents in test W3. The top of the cavity was left open in all tests. Otherwise, temperatures measured would be extremely high due to the trapped hot gases and smoke inside the cavity. Moreover, they were supposed to move upwards in a continuous cavity which runs through tens of stories in reality.

Smoke and hot gases were observed to be flowing upwards, affecting either the upper part of the outer test panel TPO or the inner test panel TPI. It was noted that opening the vent on wooden TPO was used for the ease of setting off the fire, as shown in Fig. 5c.

Large quantity of smoke was generated in the tests, explaining why a hood and exhaust duct had to be installed on top of the test rig. However, mechanical extraction system was not provided without affecting the fire-induced flow. Moreover, flame was coming out from the fire chamber to the cavity as shown in Fig. 6.

Fig. 6: Flame coming out from the fire chamber

Modification was made after the tests (W1 to W7), i.e. a 15 cm high front vent FV was left at the bottom of the test panel TPO. The purpose of it was to allow entrainment of air since there should be natural or mechanical air movement throughout the cavity in practical case. However, in view of the site constraint, it was unable to raise the whole test rig to achieve this. Leaving an opening at the lowest part became an alternative.

In the last test G1, 3.5 mm thick glass panes of size 2 m x 1.5 m commonly used was utilized by fixing several pieces to give panels of full height. Wood frames were used to stabilize the glass panes. Performance of glass in a double-skinned façade exposed under heat was demonstrated and bifurcation pattern could be observed.

4. EXPERIMENTAL RESULTS

Surface temperature and heat flux were recorded during the tests and the glass behavior under the particular heat environment was observed.

- **Temperature profile of test panels**

The results of the ten burning tests are summarized in Table 1. The temperature at points TC1 to TC4 decreased with height. Point TC1 had the highest temperature in comparing with the other three. On test panel TPI, temperature at TC6 was higher than at TC5 in general. That means the temperature on the inner test panel TPI depends on the distance from the fire chamber. By comparing the temperature on the two test panels, the smoke and flame movement or inclination inside the cavity can be anticipated. For tests W1 to W6, points TC1 to TC6 were located approximately at the same level from the ground. However, temperature at TC1 was higher than at TC6. On the other hand, for tests W7 to G1, TC1 and TC5, and TC2 and TC6 were more or less at the same level. Temperatures at the points on the outer test panel TPO were also higher than those on the inner test panel TPI, as shown in Figs. 7 to 9, for tests W8, W9 and G1. Moreover, the difference between TC1 and TC5 was larger than that between TC2 and TC6, though their distances were identical. Flame and smoke might move towards the outer skin TPO in this respect.

Among all the temperature measuring points, point TC1 had the highest temperature. Opening the front vent FV in the last three burning tests (W8, W9 and G1) is considered to be a more realistic setup. The maximum temperatures at TC1 in these tests were about 170°C to 180°C, giving a temperature rise of 145°C to 155°C. The lowest temperature on both panels TPI and TPO was found at TC4, which was the point facing the opening of the fire chamber directly.

The temperature profiles for tests W8, W9 and G1 are shown in Figs. 7 to 9. Tests W8 and W9 were carried out with wood panels; whilst G1 was conducted using glass panel. It was discovered that the two tests with wood panels took more than 3 minutes to reach the highest temperature. Test G1 with glass took more than 4 minutes to give the highest value. It is noted that the test preparation, such as pouring fuel and setting off the fire, was included in the time measurement.

Temperatures measured from the ceiling of the fire chamber were extremely high in tests W3 to W7 with the back vent BV closed. For the other tests, sufficient air supply was provided by the back vent BV of the fire room which resulted in complete burning. Large quantity of smoke and hot gases moved towards the cavity like the arrangement of fire place with a chimney.

- **Heat flux profile**

Only one heat flux meter was available in this experiment due to limitation of resources. It was located on the outer test panel TPO as illustrated in Fig. 4. By positioning it directly to face the fire source, the highest incident heat flux onto the outer skin from the fire chamber can be measured. The heat flux profiles of the two tests are shown in Fig. 10. The maximum heat flux measured in tests W8 and W9 was about 5 kWm^{-2}.

- **Glass performance**

Glass performance was observed in test G1. Cracking occurred on the outer panel TPO. The middle pane suffered the most serious cracking where it was initiated at the bottom of the pane. There were several crack bifurcation patterns, including one loop and some long cracking lines running up to the top of the pane. On the other hand, there was only one cracking line running through the pane on the uppermost one and two running through the lowest one. There was however no observed bifurcation pattern on the glass panel TPI. Fallout of glass pane was not encountered in this test. Cracking patterns are shown in Fig. 11. Time to give the first crack was not recorded in this study.

5. DISCUSSION

From the results, points TC1 and TC6 had the highest temperature on TPO and TPI respectively. On the other hand, when comparing points on the same height, outer panel TPO would experience higher temperature than inner panel TPI. It is also shown in Figs. 7 to 9 that the difference between TC1 and TC5 was larger than that between TC2 and TC6. All these implied that hot gases moved towards the outer skin of the double-skinned façade and had an inclination to the upper part, as illustrated in Fig. 1a.

There should be mechanical or natural ventilation inside the cavity of this building feature. A 15 cm high front FV opening was created to introduce natural ventilation into the cavity to act as if air moves from the floors below. Air moving up would cool down the internal space to some extent. In addition, smoke and hot gases coming out from the fire chamber would tilt upwards due to buoyancy and affect TC4 to a lesser extent. Therefore, TC4 had the lowest temperature.

Table 1: Summary of results

Test no.	Mass of fuel burnt (ml)	Time (s)	Opening conditions (Closed – C Open – O)			Max. heat flux (kWm^{-2})	Test panel surface temperature (°C)															
							Min.								Max.							
							TPO				TPI		Ceiling		TPO				TPI		Ceiling	
			FV	BV	SV		TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8
W1	1000	900	C	O	C	1.68	18	14	14	10	17	16	14	18	107	96	71	47	88	88	71	82
W2	2000	600	C	O	C	3.67	16	18	13	17	16	15	15	17	158	147	107	72	119	125	67	73
W3	2000	600	C	C	O	1.57	23	19	20	17	22	22	47	47	127	78	50	44	113	116	494	489
W4	2000	600	C	C	C	0.96	19	20	15	16	18	19	23	21	146	141	117	104	126	127	525	479
W5	3000	600	C	C	C	0.92	18	20	16	20	22	20	41	40	176	170	148	131	154	156	589	545
W6	5000	600	C	C	C	0.98	20	20	18	18	21	20	54	55	243	235	209	183	216	214	669	644
W7	3000	900	C	C	C	N/A	21	19	17	15	19	20	19	17	222	216	178	154	160	181	693	698
W8	5000	676	O	O	C	5.46	23	21	19	19	22	21	21	19	171	150	130	119	124	147	102	85
W9	5000	793	O	O	C	5.11	21	23	20	20	21	17	31	31	180	173	116	107	127	148	122	105
G1	5000	867	O	O	C	N/A	18	18	17	18	16	17	17	17	176	160	116	104	144	138	98	75

Remarks: Fuel type: gasoline
Configuration of fuel container: circular (diameter 0.5 m)
Location of fuel container: centre of fire chamber
Test panel: W1-W9 using wood panels, G1 using glass panel
Openings: FV of area 0.3 m^2 (0.15 m by 2.0 m), BV of area 1 m^2 (0.5 m by 2.0 m) and SV of area 0.5 m^2 (0.5 m by 1.0 m)

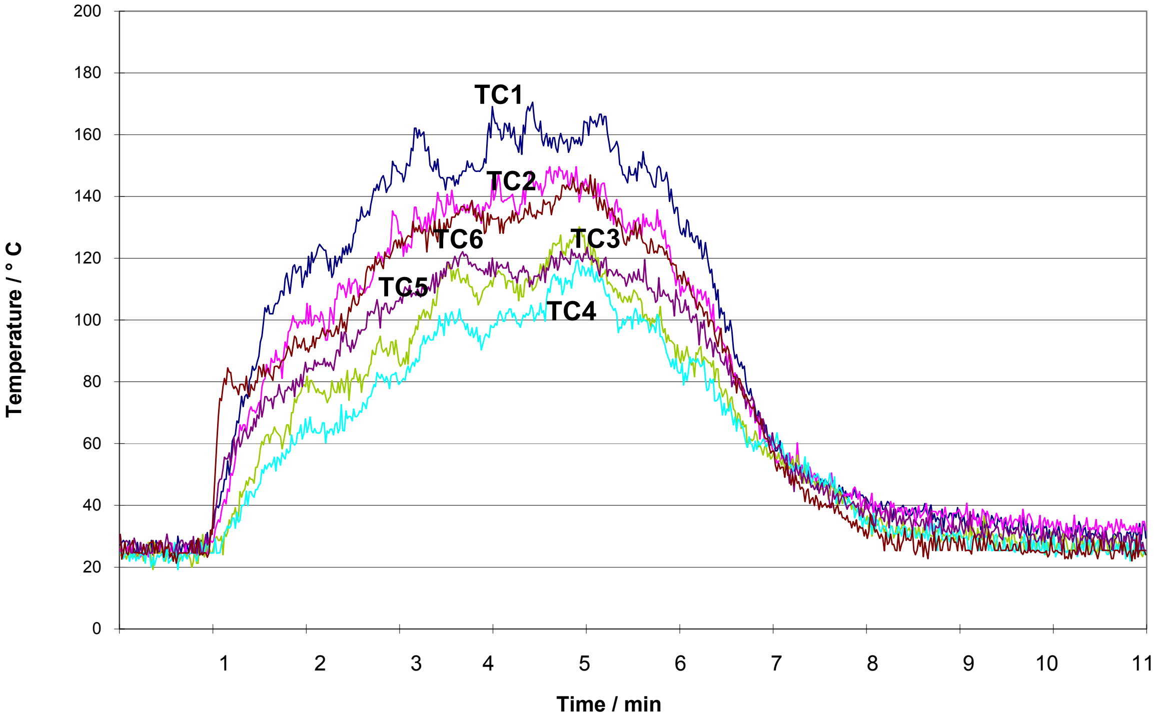


Fig. 7: Temperature profiles at TC1 to TC6 for test W8

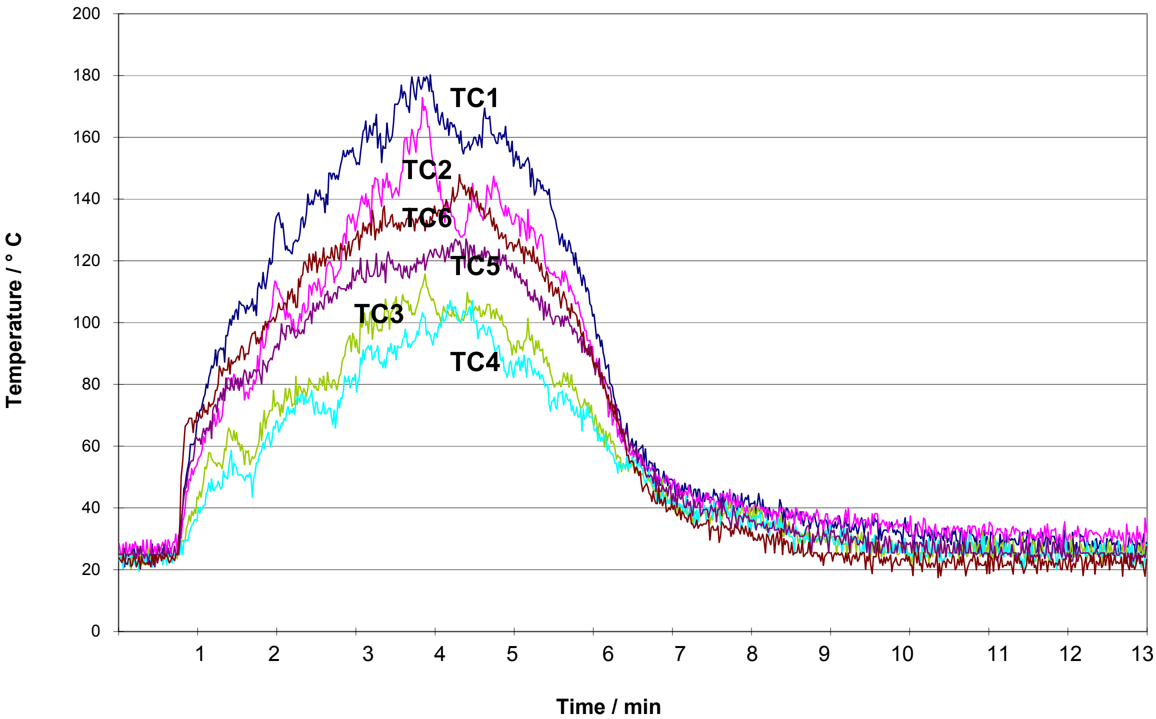


Fig. 8: Temperature profiles at TC1 to TC6 for test W9

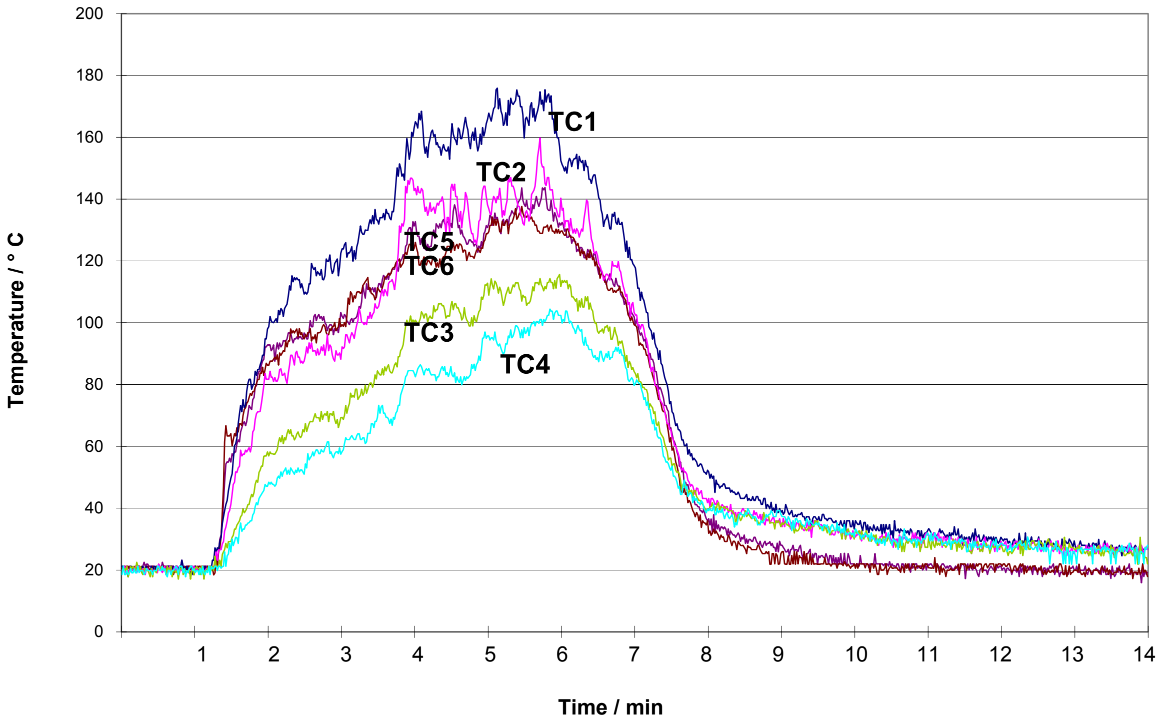


Fig. 9: Temperature profiles at TC1 to TC6 for test G1

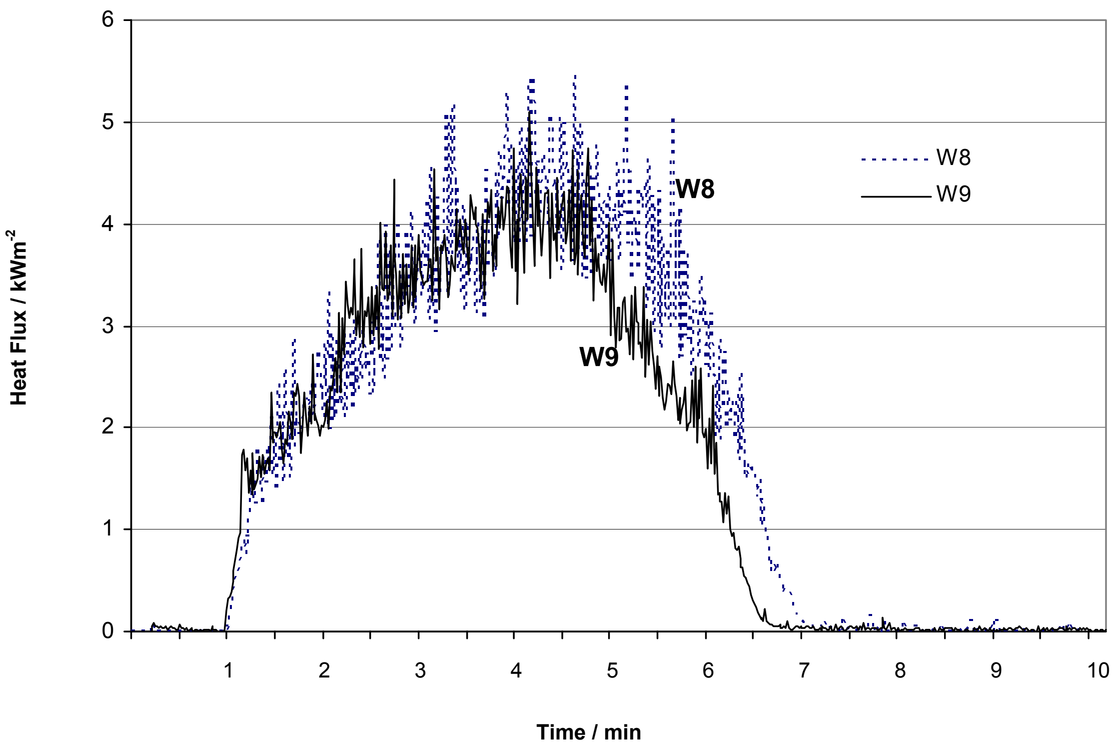
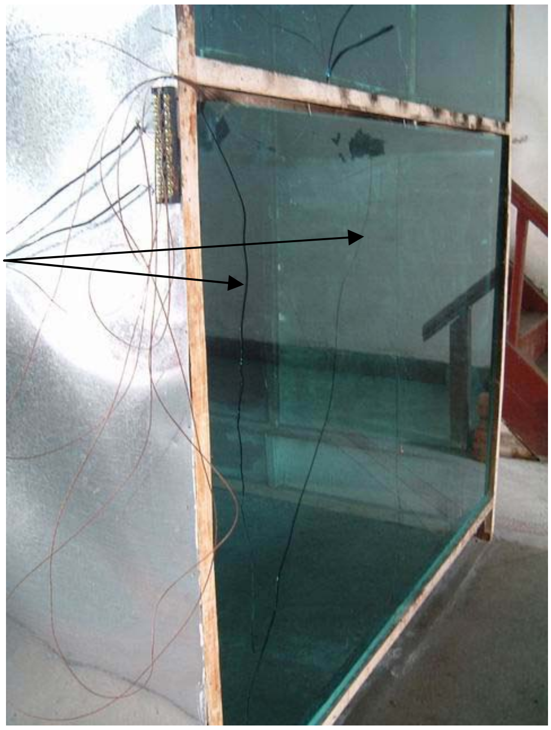


Fig. 10: Heat flux on TPO

(a) Middle pane



(b) Lower pane

(c) Another view

Fig. 11: Bifurcation patterns at the outer glass pane

Point TC1 was the hottest point among all the measuring points. The surface temperature was about 170°C to 180°C in the three tests W8, W9 and G1. However, it was shown that its temperature would be higher in the burning tests without opening the front and back vents FV and BV. It is because hot gases were trapped inside and there was no air supply to cool down the internal space. A bigger fire size might give higher temperature and more severe damage to the glass panels. It was found that temperature over 400°C could cause glass fallout [4].

It took a bit longer time for test G1 to reach the highest temperature than for tests W8 and W9. Test G1 was carried out by using glass panel which is different from wood panels. Glass is transparent to thermal radiation whilst wood is opaque to it. Therefore, some of the heat might lose to the surroundings through the glass panels and the internal temperature was then decreased.

Thermal stress across test panel TPO would be higher due to higher temperature exposure. As a result, cracking patterns only appeared on test panel TPO. The middle glass panes suffered the most serious damage among the three glass panes on TPO. The cracks were caused by a heat flux of less than 5 kWm^{-2} and temperature of less than 170°C. Such results were found to be consistent with the overseas studies [8] that the first cracking occurred when the bulk glass temperature was at about 110°C and the heat flux was about 3 kWm^{-2}. Several cracking lines initiated from the edges of the panes and one cracking line at the bottom of the middle pane extended to create a loop where a small piece of glass was about to fall out but remained intact finally. Other long cracking lines extended through the glass panes. Smoke and hot gases were supposed to tilt towards the outer skin with certain inclination from the measured temperature distribution, which is coincident with the distribution of bifurcation patterns.

Due to limited resources, the outer skin of the glass panel was composed by three smaller glass panes, as shown in Figs. 4b and 6. It is believed that glass pane of smaller area would be stiffer than that of larger area [4]. Large piece of glass would undergo larger temperature difference between the edge and the centre and higher thermal stress would be resulted. In this experiment, it has already been demonstrated that the glass panels cannot endure high heat environment. Cracks would be generated and fallout of pieces is likely to occur. It would be very risky to the neighboring buildings and environment in reality.

In this study, one scenario was achieved where cracks appeared on the outer skin only but not on the inner skin. The severity should be smaller than that appears on the inner skin since the affected area would not be extended to other stories. The only concern in this case is then the glass pieces would be harmful to the pedestrians. The direction of smoke movement depends on a number of factors, say heat release rate (HRR), the opening to cavity and the depth of the cavity. Many other possible scenarios would occur at other conditions. Further studies are required to fully understand the fire safety environment for this architectural feature.

The depth of cavity in this study was set to 2 m which can be perceived as the maximum typical size in real development. Further study should make it less than 2 m. The depth of the cavity would definitely affect the inclination of the exhausted gases. Narrower cavity should be more influential to the smoke spreading while an oversized shaft would act like an open space. One of the driving forces for air movement is the stack/chimney effect due to temperature difference between the indoor and outdoor space. When fire comes out from the fire floor, the cavity would act like a chimney. Its significance is affected by the height of the vertical shaft or the ratio of the width and height of the cavity. The ratio in this study may be too large that the cavity was not like an enclosed space. The upward force pushing the hot gases was therefore insignificant and thus the horizontal component of momentum appeared in a more dominant way as shown in the smoke movement.

Fire size plays a key role in determining the quantity of smoke produced and thus the movement of toxic hot gases. The vertical momentum would be increased by the quantity of smoke. By varying HRR, it may also give a different picture on the inclination of hot gases. The maximum HRR given by 5000 ml gasoline in this test was about 0.55 MW.

The breakout of glass should most probably appear at the top of the story since hot gases would form a layer at the ceiling of the fire room. Smoke coming out from the vent near the ceiling could easily affect the glass panel on the adjacent floor. In this experimental study, the opening across the fire chamber and cavity was created 0.6 m below the ceiling of the fire chamber which was of 2.1 m high. The spreading of flame and smoke were obstructed by the vertical wall above the opening which acted like a reservoir screen. The spreading was reduced to a certain extent and the upward force was also affected.

There is ventilation inside the cavity in a real construction to remove the accumulated heat [2]. The normal convective force might be higher than that naturally introduced by the 15 cm high front vent FV in the tests. It is believed that it also helps pushing up and affecting the direction of smoke movement.

Glass species would be significant to the glass behavior, for instance, tempered glass has four times the strength of annealed glass [9]. But of course, its cost would be much higher than the ordinary counterparts. Thickness of glass is also determinant but the strength is, again, cost-oriented. Good combinations of different glass types at inner and outer skins, together with the optimum width of cavity are important to the fire safety of this building feature and also the capital cost.

As required by the existing regulations [10], a vertical spandrel of not less than 900 mm should be constructed below the opening for the sake of fire safety protection. The upper floor can effectively evade from the attack of hot smoke. Inner glass wall can be visualized as a single-glazing where the same protection should be also taken into account. Materials of higher strength, say tempered glass, could be selected for construction of this barrier. However, the vertical shaft is enclosed by the outer skin, the temperature and pressure gradient are different from the ambient. Smoke coming out from the fire chamber cannot be diluted and cooled down and a higher risk is resulted.

Scenarios are influenced by a number of factors as discussed. A preliminary test as demonstrated in this paper can give some ideas for further studies which are strongly required for an in-depth understanding of double-skinned façade.

6. CONCLUSION

Smoke and flame spreading to the cavity of a double-skinned façade were studied. The possibility of damaging this building feature was investigated. A probable detrimental situation is flame impingement onto the inner glass panes on the adjacent floors. Cracking on the internal layer of double-skinned façade would expand the affected area and thus more occupants would be endangered. The cavity between two layers of glass becomes an effective channel for spreading of smoke and flame, with the assistance of natural or mechanical ventilation in accompany with the space to take away accumulated solar heat gain. A simple experimental setup was used in this study to examine the inclination of gases inside the cavity, whether it is moving vertically upwards from the fire room or tilting towards the outer skin at an angle.

Though a less risky situation was resulted in this study, i.e. the outer skin instead of inner skin was damaged, it was only a very preliminary study which represented a particular scenario. Cavity width of 2 m might be a safe value for this new feature. Undesirable fire scenarios might be caused by a value less than that. The critical value to cause the breakout of the inner skin can only be achieved by future studies.

Through this preliminary study, the potential fire safety problems of double-skinned façade are disclosed. In-depth studies are strongly required following the popularity of this new green feature.

ACKNOWLEDGEMENT

The project is funded by a PolyU research studentship.

REFERENCES

1. W.Y. Hung and W.K. Chow, "Fire safety in new architectural design associated with the extensive use of glass", 2003 International Symposium on Fire Science and Fire-Protection Engineering Proceedings, China Fire Protection Association, Beijing, China, pp. 389-396 (2003).
2. M. Kragh, "Mechanically ventilated double skin facades", Advances in Building Technology: Proceedings of the International Conference on Advances in Building Technology, 4-6 December 2002, Hong Kong, China, Vol. 2, pp. 1233-1240 (2002).
3. J. Jones, T. Messadi and S.S. Li, "Experimental study of the cooling season performance of ventilated double-glass envelope cavities", International Building Physics Conference, Tools for Design and Engineering of Buildings, 18-21 September 2000, Eindhoven, The Netherlands, pp. 357-365 (2000).
4. T.J. Shields, G.W.H. Silcock and M.F. Flood, "Performance of a single glazing assembly exposed to a fire in the centre of an enclosure", Fire and Materials, Vol. 26, pp. 61-75 (2002).
5. T.J. Shields, G.W.H. Silcock and S.K.S. Hassani, "The behavior of double glazing in an enclosure fire", Journal of Applied Fire Science, Vol. 7, No. 3, pp. 267-286 (1997/98).
6. W.Y. Hung and W.K. Chow, "Architectural features for the environmental friendly century", Sustainable Building 2002 Conference, Oslo, Norway, September (2002).
7. W.K. Chow, "Fire safety in green or sustainable buildings: Application of the fire engineering approach in Hong Kong", Architectural Science Review, Vol. 46, No. 3, pp. 297-303 (2003).
8. T.J. Shields, G.W.H. Silcock and M.F., Flood, "Performance of single glazing elements exposed to enclosure corner fires of increasing severity", Fire and Materials, Vol. 25, pp. 123-152 (2001).
9. BS 6262: Part 4, Code of Practice for Glazing for Buildings – Safety Related to Human Impact, British Standard, British Standard Institution, UK (1994).
10. Code of Practice for Fire Resisting Construction, Buildings Department, Hong Kong (1996).